Designation: E1074 − 15

Standard Practice for
Measuring Net Benefits and Net Savings for Investments in Buildings and Building Systems[1]

This standard is issued under the fixed designation E1074; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

The net benefits (NB) and net savings (NS) methods are part of a family of economic evaluation methods that provide measures of economic performance of an investment over some period of time. Included in this family of evaluation methods are life-cycle cost analysis, benefit-to-cost and savings-to-investment ratios, internal rates of return, and payback analysis.

The NB method calculates the difference between discounted benefits and discounted costs as a measure of the cost effectiveness of a project. The NS method calculates the difference between life-cycle costs as a measure of the cost-effectiveness of a project. The NB and NS methods are sometimes called the net present value method. The NB and NS methods are used to decide if a project is cost effective (net benefits greater than zero, or net savings greater than zero), or which size, or design, competing for a given purpose is most cost effective (the one with the greatest net benefits, or the one with the greatest net savings).

1. Scope

1.1 This practice covers a recommended procedure for calculating and interpreting the net benefits (NB) and net savings (NS) methods in the evaluation of building designs and systems.

1.2 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E631 Terminology of Building Constructions

E833 Terminology of Building Economics

E917 Practice for Measuring Life-Cycle Costs of Buildings and Building Systems

E964 Practice for Measuring Benefit-to-Cost and Savings-to-Investment Ratios for Buildings and Building Systems

E1057 Practice for Measuring Internal Rate of Return and Adjusted Internal Rate of Return for Investments in Buildings and Building Systems

E1121 Practice for Measuring Payback for Investments in Buildings and Building Systems

E1185 Guide for Selecting Economic Methods for Evaluating Investments in Buildings and Building Systems

E1369 Guide for Selecting Techniques for Treating Uncertainty and Risk in the Economic Evaluation of Buildings and Building Systems

E1765 Practice for Applying Analytical Hierarchy Process (AHP) to Multiattribute Decision Analysis of Investments Related to Buildings and Building Systems

E1946 Practice for Measuring Cost Risk of Buildings and Building Systems and Other Constructed Projects

E2204 Guide for Summarizing the Economic Impacts of Building-Related Projects

2.2 *Adjuncts:*[3]

Discount Factor Tables Adjunct to Practices E917, E964, E1057, E1074, and E1121

---

[1] This practice is under the jurisdiction of ASTM Committee E06 on Performance of Buildings and is the direct responsibility of Subcommittee E06.81 on Building Economics.

Current edition approved May 1, 2015. Published June 2015. Originally approved in 1985. Last previous edition approved in 2009 as E1074 – 09. DOI: 10.1520/E1074-15.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from ASTM International Headquarters. Order Adjunct No. ADJE091703.

3. Terminology

3.1 *Definitions*—For definitions of general terms related to building construction used in this practice, refer to Terminology E631; and for general terms related to building economics, refer to Terminology E833.

4. Summary of Practice

4.1 This practice is organized as follows:

4.1.1 *Section 2, Referenced Documents*—Lists ASTM standards referenced in this practice.

4.1.2 *Section 3, Definitions*—Addresses definitions of terms used in this practice.

4.1.3 *Section 4, Summary of Practice*—Outlines the contents of the practice.

4.1.4 *Section 5, Significance and Use*—Explains the application of the practice and how and when it should be used.

4.1.5 *Section 6, Procedures*—Summarizes the steps in making NB (NS) analysis.

4.1.6 *Section 7, Compute NB (NS)*—Describes calculation procedures for NB (NS).

4.1.7 *Section 8, Anaylsis of NB (NS) Results and the Decision*—Discusses the decision criterion and the treatment of uncertainty, risk, and unqualified effects.

4.1.8 *Section 9, Applications*—Explains circumstances under which the NB (NS) method is appropriate.

4.1.9 *Section 10, Report*—Identifies information that should be included in a report of a NB (NS) analysis.

5. Significance and Use

5.1 The NB (NS) method provides a measure of the economic performance of an investment, taking into account all relevant monetary values associated with that investment over the investor's study period. The NB (NS) measure can be expressed in either present value or equivalent annual value terms, taking into account the time value of money.

5.2 The NB (NS) method is used to decide if a given project is cost effective and which size or design for a given purpose is most cost effective when no budget constraint exists.

5.3 The NB (NS) method can also be used to determine the most cost effective combination of projects for a limited budget; that is, the combination of projects having the greatest aggregate NB (NS) and fitting within the budget constraint.

5.4 Use the NB method when the focus is on the benefits rather than project costs.

5.5 Use the NS method when the focus in on project savings (that is, reductions in project costs).

6. Procedures

6.1 The recommended steps for applying the NB (NS) method to an investment decision are summarized as follows:

6.1.1 Make sure that the NB (NS) method is the appropriate economic measure (see Guide E1185),

6.1.2 Identify objectives, alternatives, and constraints,

6.1.3 Establish assumptions,

6.1.4 Compile data,

6.1.5 Convert cash flows to a common time basis (discounting),

6.1.6 Compute NB (NS)[4] and compare alternatives, and

6.1.7 Make final decision, based on NB (NS) results as well as consideration of risk and uncertainty, unquantifiable effects, and funding constraints (if any).

6.2 Since the steps mentioned in 6.1.2 – 6.1.5 are treated in detail in Practice E917 and briefly in Practices E964 and E1121, they are not discussed in this practice. In calculating NB (NS), these four steps should be followed exactly as described in Practice E917. The remainder of this practice focuses on the computation, analysis, and application of the NB (NS) measure. A comprehensive example of the NB method applied to a building economics problem is provided in Appendix X1. A comprehensive example of the NS method applied to a building economics problem is provided in Appendix X2.

7. NB (NS) Computation

7.1 Computation of NB for any given project requires the estimation, in dollar terms, of differences between benefits, and differences between costs, for that project relative to a mutually exclusive alternative. Computation of NS for any given project requires the estimation, in dollar terms, of the difference between life-cycle costs for the project relative to a mutually exclusive alternative. The mutually exclusive alternative may be a similar design/system of a different scale, a dissimilar design/system for the same purpose, or the do nothing case. Denote the alternative under consideration as A_j and the mutually exclusive alternative to be used for purposes of comparison as A_k. Alternative A_k is typically the do nothing case or the project with the lowest first cost, which may or may not be the same project. But the analyst can choose any of the mutually exclusive alternatives as the base case against which to compare alternatives. Benefits can include (but are not limited to) revenue, productivity, functionality, durability, resale value, and tax advantages. Costs can include (but are not limited to) initial investment, operation and maintenance (including energy consumption), repair and replacements, and tax liabilities.

7.2 Eq 1 is used to compute the present value of net benefits ($\mathrm{PVNB}_{j:k}$) for the proposed project relative to its mutually exclusive alternative.

$$\mathrm{PVNB}_{\mathrm{j:k}} = \sum_{t=0}^{N} \left(B_t - \bar{C}_t\right)/(1+i)^t \qquad (1)$$

where:

B_t = dollar value of benefits in period t for the building or system being evaluated, A_j, less the counterpart benefits in period t for the mutually exclusive alternative against which it is being compared, A_k,

$\bar{C}_t$ = dollar costs, including investment costs, in period t for the building or system being evaluated, A_j, less the counterpart costs in period t for the mutually exclusive alternative against which it is being compared, A_k,

---

[4] The NIST Building Life-Cycle Cost (BLCC) Computer Program helps users calculate measures of worth for buildings and building components that are consistent with ASTM standards. The program is downloadable from http://www.eere.energy.gov/femp/information/download_blcc.html.

N = number of discounting time periods in the study period, and

i = the discount rate per time period.

7.3 Use Eq 2 to convert the present value of net benefits to annual value terms, where N is the number of years in the study period and i is the discount rate.

$$\mathrm{AVNB}_{j:k} = \mathrm{PVNB}_{j:k} \cdot [(i(1+i)^N)/((1+i)^N - 1)] \tag{2}$$

where $\mathrm{AVNB}_{j:k}$ = annual value of net benefits.

7.4 Use Eq 3 to compute the present value of net savings ($\mathrm{PVNS}_{j:k}$) for the proposed project, A_j, relative to its mutually exclusive alternative, A_k. The terms appearing in Eq 3 are based on the life-cycle cost (LCC) method, Practice E917. Subtract from project costs in the year in which they occur any pure benefits (for example, increased rental income due to improvements) in the LCC calculation.

$$\mathrm{PVNS}_{j:k} = \mathrm{LCC}_k - \mathrm{LCC}_j \tag{3}$$

where:

LCC_j = the life-cycle costs of the alternative under consideration, A_j, and

LCC_k = the life-cycle costs of the mutually exclusive alternative, A_k.

7.5 Use Eq 4 to convert the present value of net savings to annual value terms, where N is the number of years in the study period and i is the discount rate.

$$\mathrm{AVNS}_{j:k} = \mathrm{PVNS}_{j:k} \cdot [(i(1+i)^N)/((1+i)^N - 1)] \tag{4}$$

where:

$\mathrm{AVNS}_{j:k}$ = annual value of net savings.

7.6 For a given problem and data set, solutions in either present value or annual value terms will be time equivalent values (although different in actual dollar values) and will result in the same investment or design decisions, provided annual values are calculated using Eq 2 for net benefits and Eq 4 for net savings.

7.7 A simple application of Eq 1 is presented in Table 1 for an initial investment of $10 000 that yields an uneven yearly cash flow over four years. (Implicitly, the mutually exclusive alternative is the *do nothing* case.) Assuming a discount rate of 15 %, the discounted cash flows yield a PVNB of $1823. (Note that the sum of net cash flows, $7000, is a much larger value, since it fails to account for the eroding value of money over time.) The larger the PVNB for a given project, the more economically attractive it will be, other things being equal.

7.8 To find the AVNB that is time equivalent to $1823, use Eq 2. The equivalent AVNB is $639.

8. Analysis of NB (NS) Results and the Decision

8.1 Use the results of the NB (NS) computation to rank order alternatives from highest to lowest NB (NS). The alternative with the highest NB (NS) is the most cost effective.

8.2 In the final investment decision, take into account not only the numerical values of NB (NS), but also uncertainty of investment alternatives relative to the risk attitudes of the investor, the availability of funding and other cash-flow constraints, any unquantified effects attributable to the alternatives, and the possibility of noneconomic objectives. (These topics are discussed in Section 10 of Practice E917.)

8.2.1 Decision makers typically experience uncertainty about the correct values to use in establishing basic assumptions and in estimating future costs. Guide E1369 recommends techniques for treating uncertainty in parameter values in an economic evaluation. It also recommends techniques for evaluating the risk that a project will have a less favorable economic outcome than what is desired or expected. Practice E1946 establishes a procedure for measuring cost risk for buildings and building systems, using the Monte Carlo simulation technique as described in Guide E1369. Practice E917 provides direction on how to apply Monte Carlo simulation when performing economic evaluations of alternatives designed to mitigate the effects of natural and man-made hazards that occur infrequently but have significant consequences. Practice E917 contains a comprehensive example on the application of Monte Carlo simulation in evaluating the merits of alternative risk mitigation strategies for a prototypical data center.

8.2.2 Describe any significant effects that remain unquantified. Explain how these effects impact the recommended alternative. Refer to Practice E1765 for guidance on how to present unquantified effects along with the computed values of NB (NS) or any other measures of economic performance.

9. Applications

9.1 The NB (NS) measure indicates that a given project is cost effective if the PVNB (PVNS) is greater than zero. If the PVNB (PVNS) is less than zero, then the project is not cost effective.

9.2 How large an investment to make (that is, what is the most economically efficient scale) is generally answered with NB (NS) analysis. The size or scale of investment is increased

TABLE 1 Calculation of Net Benefits

Year, t	Benefits, B_t, dollars	Costs, $\bar{C}_t$, dollars	Net Cash Flow $B_t - \bar{C}_t$, dollars	SPV Factor[A] for $i = 15\ \%$	PVNB, dollars
0	0	10 000	−10 000	1.000	−10 000
1	4 000	3 000	+1 000	0.8696	+870
2	11 500	4 500	+7 000	0.7561	+5 293
3	10 000	4 000	+6 000	0.6575	+3 945
4	8 000	5 000	+3 000	0.5718	+1 715
Total	33 500	26 500	+7 000		+1 823

[A] To find the PVNB of the net cash flow for each discounting period, the single present value (SPV) discount factor is multiplied times the net cash flow. For an explanation of discounting factors and how to use them, see Discount Factor Tables.

until the PVNB (PVNS) is maximized. Typical size or scale examples from the building industry include *(1)* how large a building to construct, *(2)* how large a dam to construct, *(3)* how much insulation to put in a house, and *(4)* how many square feet of collector area to install in a solar energy system.

9.3 Fig. 1 illustrates graphically how the NB method is used to choose the economically efficient level of energy conservation in a building (that is, where the PVNB is maximized). Conservation costs, in present value terms, are shown to increase at an increasing rate as the physical quantity of inputs to conserve energy (Q_i) is increased (for example, increased insulation). Conservation benefits (in present value terms), as measured by dollar energy savings, also increase with additional inputs to energy conservation, but at a decreasing rate. The difference between these dollar conservation benefits and costs at any given level of conservation inputs is the PVNB. The level of energy conservation where the PVNB is maximized is Q_e. Any smaller (Q_1) or larger investments (Q_2 or Q_3) than Q_e would be economically inefficient, because the potential PVNB (profit) is greatest at Q_e (Note 1). Therefore, when using PVNB as a guide, the economically efficient level of insulation for a building is found by increasing applications of insulation until the PVNB is maximized.

NOTE 1—The efficient size could be smaller than Q_e if the investment budget were limited and if other projects were available with incremental benefit-to-cost ratios greater than one.

9.4 Fig. 1 also illustrates the application described in 9.1. That is, any level of conservation inputs portrayed in Fig. 1 within the bounds of zero and Q_3 would be a cost-effective investment.

9.5 The NB (NS) method is also used to compare projects or designs competing for the same purpose to see which is most economically efficient. Typical examples from the building industry include: (*1*) how to select between single, double, or triple glazing; (*2*) how to choose between a solar energy system and a conventional energy system; and (*3*) how to choose between a large dam and a small dam with levees to provide flood control. The most economically efficient project in each case would be the one with the greatest PVNB or PVNS, depending on the method utilized (Note 2). Applying Eq 1, for example, to the selection of a flood control project, if PVNB is greater for the small dam and levees than for the large dam, then the small dam and levees are the economically preferred system.

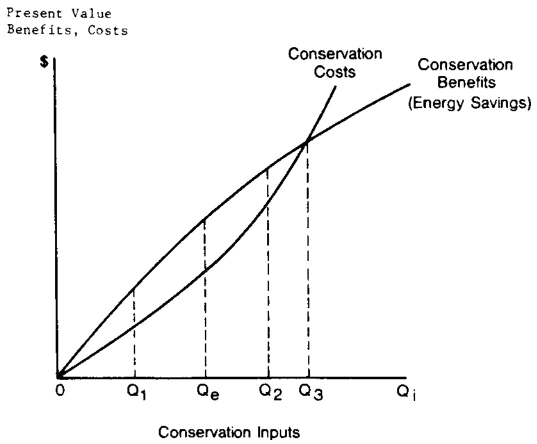

FIG. 1 Finding the Level of Energy Conservation That Maximizes the PVNB

NOTE 2—In these applications of NB (NS) analysis, it is assumed that the initial cost of the alternatives considered does not exceed the available budget.

9.5.1 In using PVNB (PVNS) to compare mutually exclusive projects (that is, a set of projects from which one alternative can be selected), a common study period is required for a valid economic comparison.

9.5.1.1 In comparing projects competing for the same purpose, the analyst must sometimes normalize the PVNB (PVNS) with respect to time in order to have a valid economic comparison. The PVNB (PVNS) of projects with identical expected lives can be compared directly. If the expected lives are different, however, adjustments are required. A common adjustment is to convert each project's life to the least common multiple of the lives of all projects under consideration. By making assumptions about reinvestment costs and earnings, a time-normalized PVNB (PVNS) can then be calculated for each project for comparison over the common study period.

9.5.1.2 A second approach is to select the relevant time horizon of the investor as the length of the study period. Then use replacements and residual values to evaluate each alternative within the common study period.

9.5.1.3 A third approach for comparing projects with unequal lives is to convert the PVNB calculated on the basis of each project's life to an annual value of net benefits (AVNB) using Eq 2. To convert the PVNS calculated on the basis of each project's life to an annual value of net savings (AVNS), use Eq 4. The AVNB (AVNS) will yield a valid economic comparison if the costs and benefits of each project are replicated exactly with each replacement.

9.6 Aggregate PVNB (PVNS) can be used to determine the most cost effective allocation of a limited budget among non-mutually exclusive projects. In general, the combination of projects with the greatest aggregate PVNB (PVNS) fitting within the budget constraint is the most cost effective allocation. In order to aggregate the NB (NS) of non-mutually exclusive projects, they must all be computed over the same study period.

10. Report

10.1 A report of a NB (NS) analysis should include the following information:

10.1.1 The objective and the alternatives considered.

10.1.2 Key assumptions and data including:

10.1.2.1 Discount rate,

10.1.2.2 Study period,

10.1.2.3 Cost data,

10.1.2.4 Benefits (savings) data,

10.1.2.5 Grants, tax deductions, and

10.1.2.6 Financing terms.

10.1.3 The tax status of the investor together with the method of treating inflation.

10.1.4 Any significant effects that are not quantified in the NB (NS) measure.

10.2 Guide E2204 presents a generic format for reporting the results of a NB (NS) analysis. It provides technical persons, analysts, and researchers a tool for communicating results in a condensed format to management and non-technical persons. The generic format calls for a description of the significance of the project, the analysis strategy, a listing of data and assumptions, and a presentation of the computed values of NB (NS) or any other measures of economic performance.

11. Keywords

11.1 benefit-cost analysis; building economics; economic evaluation methods; engineering economics; life-cycle cost analysis; net benefits; net savings

APPENDIXES

(Nonmandatory Information)

X1. USING PRESENT VALUE NET BENEFITS TO EVALUATE RESIDENTIAL SPRINKLER SYSTEMS[5]

X1.1 *Background*—Appendix X1 uses the net benefits method to measure the expected economic performance of a fire sprinkler system installed in a newly constructed, single-family dwelling in the United States. Two alternatives are considered: (1) a dwelling equipped with smoke alarms, and (2) an identical dwelling equipped with smoke alarms and a sprinkler system. The objective is to determine if the purchase of the automatic fire sprinkler system is cost-effective. Three prototypical house types are considered for analyzing the economic performance of a residential sprinkler system: (1) a two-story colonial with basement, but not including the garage; (2) a three-story townhouse with basement; and (3) a single-story ranch.

X1.2 *Data and Assumptions*—The benefits experienced by residents of single-family dwellings with sprinkler systems include reductions in the following: the risk of owner/occupant fatalities and injuries, homeowner insurance premiums, uninsured direct property losses, and uninsured indirect costs. The primary costs examined are for initial purchase and installation of the sprinkler system. The measure of economic performance, the PVNB, compares differently timed benefit and cost cash flows, accruing to an owner/occupant, by discounting them to a reference point in time. All dollars presented are in 2005 constant dollars. PVNB is calculated by subtracting present value costs from the present value benefits. Data and assumptions needed to evaluate the decision are summarized in Table X1.1.

X1.2.1 *Analysis Strategy*—Two types of analyses are used to evaluate the merits of residential sprinklers. First, a baseline analysis is performed in which all values are fixed. Second, a sensitivity analysis employing Monte Carlo simulation is performed in which key input variables are allowed to vary in combination according to an experimental design (see Guide E1369). These analysis types complement and reinforce each other.

X1.2.2 *Benefits*—The quantified benefits of a fire sprinkler system used in a single-family dwelling are based on reported fire incident data contained within the U.S. Fire Administration's National Fire Incident Reporting System 5.0 (NFIRS 5.0) (**2**),[6] and calibrated with reported data based on the National Fire Protection Association's annual survey of fire departments (Hall and Harwood, 1989) (**3**), over the period of 2002 to 2005 (Ahrens, 2007) (**4**). This study period was selected due to the relative completeness of fire incident records nationwide, thus ensuring that the nationwide trends and patterns used in this analysis are representative of U.S. fire risks. Over the 2002 to 2005 study period, houses equipped with smoke alarms and a wet-pipe sprinkler system (that is, a system fully-charged with water at all times) experienced 100 % fewer owner/occupant fatalities, 57 % fewer owner/occupant injuries, and 32 % less direct property losses and indirect costs resulting from fire than houses equipped only with smoke alarms. In addition, homeowners of dwellings with fire sprinkler systems received an added bonus of an 8 % reduction in their homeowner insurance premium per year. The monetized value of a residential fire sprinkler system, over a 30-year analysis period, yields homeowners $4994 in present value benefits. In the baseline analysis, the colonial, townhouse, and ranch-style house were all assigned the same economic benefits from installation of a residential fire sprinkler system. The assignment of equal economic benefits was due to an inability to identify differential benefits among the

TABLE X1.1 Data and Assumptions for Analysis of Residential Sprinklers

Study Period	30 Years
Discount Rate (Real)	4.80 %
Base Year	2005
Investment Cost Data	
Colonial	$2 075
Townhouse	$1 895
Ranch	$829
Benefits per	
Fatality Averted	$7.94 million
Injury Averted	$171 620
Direct Property Loss Averted	$4 398
Indirect Costs Averted	$880
Insurance Credit (Annual)	$60

---

[5] Appendix X1 is based largely on a National Institute of Standards and Technology (NIST) report (Butry, Brown, and Fuller, 2007) (**1**).[6]

[6] The boldface numbers in parentheses refer to a list of references at the end of this standard.

three house types. This is because the NFIRS 5.0 data did not differentiate housing type or number of stories, other than indicating it was a one- to two-family dwelling. However, one might expect more benefits to be gained with sprinklers in a two-story house, due to the increased potential for keeping exit routes open. Two key benefits—the value of a statistical life and the value of a statistical injury—merit a closer examination. Assigning a dollar value to a statistical life saved or injury averted has become a generally accepted part of economic methodology. The magnitude of the values is often a critical input to economic analysis because a reduction of the risk of death or injury may be a substantial benefit component. However, empirical estimates of the value of life continue to be subject to controversy and inconsistency. For example, basing the value of a life on the present value of earnings potential—a measure that is sometimes used—tends to result in comparatively low values for the young and the old and, in our present economy, for women and non-Caucasians. Using court-assigned values for death, pain, and injury inflicted—another approach—results in widely variable amounts. The value of saving lives and reducing pain and injury implicitly assigned by government programs also vary widely.

X1.2.2.1 *Value of a Statistical Life*—One approach that is considered to be consistent with economic theory is based on the willingness-to-pay concept. Willingness-to-pay values are computed according to how much decision makers are willing to invest to reduce their risk of death or injury by a certain fraction. Using evidence on labor and product market choices that involve implicit tradeoffs between risk and wage or between risk and price, economists have developed estimates of the value of a statistical life typically ranging from $4 million to $9 million with a median value of about $7 million (in 2000 dollars) (Viscusi and Aldy, 2003) (**5**). The inflation adjusted median value of a statistical life, $7.94 million (in 2005 dollars), is used in this analysis.

X1.2.2.2 *Value of a Statistical Injury*—The same willingness-to-pay approach that is used to estimate the value of a statistical life saved can be used to estimate the value of a statistical injury averted. In a survey of 31 studies from the U.S. labor market and eight studies of labor markets outside the United States, Viscusi and Aldy (2003) (**5**) found estimates ranging up to $191 000 with most of the estimates between $20 000 and $70 000 (in 2000 dollars). The U.S. estimates are mostly based on job-related injury rates and lost workday rates from the Bureau of Labor Statistics and not specifically on fire-related injuries. The U.S. Consumer Product Safety Commission (CPSC) conducted two studies of residential fire injuries associated with mattresses and upholstered furniture. These two studies found estimates of $150 000 (in 2005 dollars) per injury from fires involving mattresses and $187 000 (in 2004 dollars) per injury from fires involving upholstered furniture (Zamula, 2005) (**6**). CPSC therefore recommended the amounts of $150 000 and $187 000 as reasonable and reliable estimates of the value of a fire-related injury averted (Zamula, 2004; Zamula, 2005; Ray et al., 1993) (**7**, **6**, **8**). As the value of an injury averted, the inflation adjusted middle value between CPSC studies on mattresses and upholstered furniture of $171 620 is used in this analysis.

X1.2.3 *Costs*—The quantified costs of a fire sprinkler system are based on the findings of NISTIR 7277 (**9**). NISTIR 7277 documented the design and installation costs of four different wet-pipe sprinkler systems within three prototypical house types. Of the alternative sprinkler systems examined in NISTIR 7277, the multipurpose network system was generally the least costly (life-cycle cost) across the three house types. The multipurpose network system was therefore selected as the fire sprinkler system examined in this analysis. The costs associated with installation of a multipurpose network sprinkler system are based on the minimum standard required by NFPA 13D (**10**). The three prototypical house types considered are: (1) a 3338 ft^2 (310 m^2) two-story colonial with basement, but not including the garage; (2) a 2257 ft^2 (210 m^2) three-story townhouse with basement; and (3) an 1171 ft^2 (109 m^2) single-story ranch. The present value costs of installation of a multipurpose network sprinkler system are estimated to be $2075 for the colonial, $1895 for the townhouse, and $829 for the ranch.

X1.3 *Baseline Analysis*—The baseline analysis uses the "best available information" to construct a fixed set of input values. These inputs are used to estimate benefits and costs.

X1.3.1 *Estimated Benefits of Multipurpose Network Sprinkler Systems in Residential Dwellings*—Table X1.2 summarizes the data used to calculate the present value benefits for the five classes of benefits described in X1.3.1.1 – X1.3.1.5. It includes benefits from fatalities averted, injuries averted, direct property losses averted, indirect costs averted, and an insurance credit due to sprinkler use within residential properties. The uniform present worth factor of 15.729 for annually recurring amounts is based on a 30-year study period and a real discount rate of 4.8 %, which reflects the real, after-tax annual rate of return on large-cap stocks over the period 1925 to 2005 (Ibbotson Associates, 2005) (**11**). Installation of a sprinkler system is expected to yield a present value benefit of $4994, over the 30-year study period. Each benefit component is detailed below.

X1.3.1.1 *Fatalities Averted*—One- and two-family dwellings with a wet-pipe sprinkler system were found to have zero fatalities in reported fires over the study period 2002 to 2005. However, field tests indicate sprinklers fail to activate 3 % of the time (Hall, 2007) (**12**), so a 100 % reduction in fatalities, over dwellings with only smoke alarms, may be too optimistic. Section X1.4 deals with this uncertainty and its effects on the results of the analysis. The value of a fatality averted is estimated at $7.94 million. Thus, a 100 % reduction in the fatality rate results in an expected present value benefit of $3726.

X1.3.1.2 *Injuries Averted*—One- and two-family dwellings with a wet-pipe sprinkler system were found to have a 57 % reduction in injuries in reported fires over dwellings equipped with only smoke alarms. The value of an injury averted is estimated at $171 620. The 57 % reduction in the injury rate results in an expected present value benefit of $225.

X1.3.1.3 *Direct Uninsured Property Loss Averted*—One- and two-family dwellings with a wet-pipe sprinkler system were found to have a 32 % reduction in direct property

TABLE X1.2 Calculation of Present Value Benefits of Wet-Pipe Sprinkler Systems[A]

	Input Parameters				Calculated Outputs	
Fatalities Averted	Probability of Fire Occurrence 0.0036	Reduction in Annual Probability of Fatality, Given Fire, Between Dwelling with Only Smoke Alarms and Dwelling with Smoke Alarms and a Sprinkler System 1.0000	Expected Number of Fatalities, per Fire, in Dwellings with Only Smoke Alarms 0.0082	Value of Statistical Life ($ million) 7.94	Annual Benefit ($) 236.86	Present Value Benefit ($) 3725.57
Injuries Averted	Probability of Fire Occurrence 0.0036	Reduction in Annual Probability of Injury, Given Fire, Between Dwelling with Only Smoke Alarms and Dwelling with Smoke Alarms and a Sprinkler System 0.5679	Expected Number of Injuries, per Fire, in Dwellings with Only Smoke Alarms 0.0403	Value of Statistical Injury ($) 171 620	Annual Benefit ($) 14.29	Present Value Benefit ($) 224.74
Direct Property Losses Averted	Probability of Fire Occurrence 0.0036	Reduction in Annual Probability of Direct Uninsured Property Loss, Given Fire, Between Dwelling with Only Smoke Alarms and Dwelling with Smoke Alarms and a Sprinkler System 0.3166	Expected Direct Uninsured Property Loss, per Fire, in Dwellings with Only Smoke Alarms 4397.96		Annual Benefit ($) 5.06	Present Value Benefit ($) 79.64
Indirect Costs Averted	Probability of Fire Occurrence 0.0036	Reduction in Annual Probability of Indirect Cost, Given Fire, Between Dwelling with Only Smoke Alarms and Dwelling with Smoke Alarms and a Sprinkler System 0.3166	Expected Indirect Cost, per Fire, in Dwellings with Only Smoke Alarms 879.59		Annual Benefit ($) 1.01	Present Value Benefit ($) 15.93
Insurance Credit	Annual Homeowner Insurance Premium ($) 753.70	Reduction in Annual Homeowner Insurance Premium for Sprinkler System 0.08			Annual Benefit ($) 60.30	Present Value Benefit ($) 948.41
				Total Present Value	$317.52	$4994.29

[A] Annual benefits are expressed in constant 2005 dollars. Present value benefits are based on a 30-year study period. Input parameters shown are rounded. Source: *Benefit-Cost Analysis of Residential Fire Sprinkler Systems* (NISTIR 7451) (Butry, Brown, and Fuller, 2007, p. 23) **(1)**.

damages over dwellings equipped with only smoke alarms. The average direct property loss was found to be $21 990 per reported fire for dwellings only equipped with smoke alarms. Because insurance is assumed to cover 80 % of any property loss (Ruegg and Fuller, 1984) (**13**), the uninsured direct property loss, responsible to the owner, was then $4398 per fire. Thus the reduction in uninsured direct property damages yields an expected present value benefit of $80 to residents in dwellings with smoke alarms and a sprinkler system.

X1.3.1.4 *Indirect Uninsured Costs Averted*—Indirect costs in one- and two-family dwellings refers to costs such as temporary shelter, missed work, extra food costs, legal expenses, transportation, emotional counseling, and child care. Indirect losses have been systematically analyzed for house fires in a study by Munson and Ohls (1980) (**14**). A review of this study leads the NFPA to use 10 % of the direct property loss as an estimate of the indirect property loss (Hall, 2004) (**15**). The average direct property loss per reported fire was found to be $21 990, meaning the estimated indirect cost per fire is $2199 for dwellings only equipped with smoke alarms. Part of the indirect loss of fires is covered by insurance. Munson and Ohls (1980) estimated that on average 60 % of indirect costs per fire are insured. Thus, the average uninsured indirect costs per fire were estimated at $880. Given that one- and two-family dwellings with a wet-pipe sprinkler system were found to have a 32 % reduction in direct property damages over the study period 2002 to 2005, a reduction in indirect costs results in an expected present value benefit of $16.

X1.3.1.5 *Insurance Premium Credit*—The U.S. average insurance premium is estimated to be $754 (Insurance Information Institute, 2007) (**16**) and sprinklers in residential dwellings are expected return homeowners upward of an 8 % to 13 % reduction in the annual premium, depending on the extensiveness of the sprinkler system (Curry, 2007) (**17**). An 8 % credit (premium reduction) is used in this analysis. The credit results in an expected present value benefit of $948.

X1.3.2 *Estimated Costs of Multipurpose Network Sprinkler Systems in Residential Dwellings*—The purchase and installation cost estimates were discussed in X1.2.3. Table X1.3 presents the installation cost estimates with material mark-up applied, where material markup increases incrementally from 50 % to 100 % (increments of 10 %). The installation cost estimates range from $2075 to $2529 for the colonial, $1895 to $2306 for the townhouse, and $829 to $1001 for the ranch. The 50 % markup is used in the baseline analysis.

X1.3.3 *Results of the Baseline Analysis*—Results of the baseline analysis show that multipurpose network sprinkler systems are economical. The expected present value of net benefits (PVNB) is estimated to be $2919 for the colonial-style house, $3099 for the townhouse, and $4166 for the ranch-style house (see Table X1.4). These baseline ("best available information") estimates indicate that a multipurpose network system is cost-effective for residential dwellings. Even when material markups are raised from 50 % to 100 %, representing a capital cost increase of between $172 for the ranch-style house and $454 for the colonial-style house, a multipurpose network system remains cost-effective.

X1.4 *Sensitivity Analysis*—Although the baseline analysis finds strong evidence of the cost-effectiveness of residential fire sprinkler systems, a sensitivity analysis is performed to measure the variability of the results to changes in the modeling assumptions and to assess the robustness of the baseline findings. The sensitivity analysis relies on a number of assumptions generated from NFIRS 5.0 (**2**), and these assumptions contain a degree of uncertainty. For instance, over the 2002 to 2005 study period of the dwellings examined, wet-pipe sprinkler systems were present in only 0.2 % of all reported structure fires. Conducting a sensitivity analysis is important because the statistics used to summarize the characteristics of dwellings with sprinklers are drawn from a small segment of the population and may be influenced by a few outlying, and unrepresentative, fire incidents. The key assumptions are varied based on observed ranges found in the data, expert opinion, and findings reported from other recent fire sprinkler studies.

X1.4.1 *Simulated Distributions*—The values (assumptions) generated from the NFIRS 5.0 (**2**) and NFPA data used in the Monte Carlo simulation are presented in Table X1.5. The values (assumptions) varied in the sensitivity analysis are the input parameters presented in Table X1.2, with the exception of the value of a statistical life, value of a statistical injury, and the insurance credit. Table X1.5 describes the simulated distributions used, along with the parameters of the distributions derived from NFIRS 5.0 2002–2005 fire incident records and calibrated using NFPA (2006) (**18**) fire statistics, unless otherwise noted in Table X1.5. Some of the parameters used were suggested by fire statistics experts at NFPA (Hall, 2007) (**12**) that meshed with historical observations, while others were motivated by the Scottsdale, AZ, sprinkler study (**19**).

X1.4.2 *Results of the Sensitivity Analysis*—The sensitivity analysis confirms the conclusions of the baseline analysis, namely that multipurpose network residential sprinkler systems are likely to be cost-effective in the single-family houses studied. Results of the sensitivity analysis are summarized in Table X1.6. For the colonial house, the mean present value of net benefits is positive, at $2468, although 15 % lower than the baseline estimate of $2919. For the townhouse, the mean present value of net benefits is positive, at $2648, although 15 % lower than the baseline estimate. For the ranch house, the

TABLE X1.3 Cost Estimate Summary Table[A]

	Material Markup ($)					
	50 %	60 %	70 %	80 %	90 %	100 %
Colonial	2075.08	2165.86	2256.64	2347.41	2438.19	2528.97
Townhouse	1895.17	1977.31	2059.45	2141.58	2223.72	2305.86
Ranch	828.66	863.18	897.69	932.21	966.72	1001.24

[A] Source: *Economic Analysis of Residential Fire Sprinkler Systems* (NISTIR 7277) (Brown, 2005, pp. 13–14) (**9**).

TABLE X1.4 Summary of Baseline Analysis Results: Analysis of a Multipurpose Network Residential Sprinkler System for the Colonial, Townhouse, and Ranch House[A]

	Colonial	Townhouse	Ranch
Benefits			
Fatalities Averted	$3725.57	$3725.57	$3725.57
Injuries Averted	224.74	224.74	224.74
Direct Uninsured Property Losses Averted	79.64	79.64	79.64
Indirect Costs Averted	15.93	15.93	15.93
Insurance Credit	948.41	948.41	948.41
Benefit Subtotal	4994.29	4994.29	4994.29
Costs			
Installation (50 % Markup)	2075.08	1895.17	828.66
Costs Subtotal	2075.08	1895.17	828.66
Present Value Net Benefits	$2919.20	$3099.11	$4165.62

[A] Source: *Benefit-Cost Analysis of Residential Fire Sprinkler Systems* (NISTIR 7451) (Butry, Brown, and Fuller, 2007, p. 26) **(1)**.

TABLE X1.5 Description of the Simulated Distributions Used in the Sensitivity Analysis[A]

Assumption	Distribution	Parameters	Notes
Probability of Fire Occurrence	Normal	Mean: 0.0036 Standard Deviation: 0.0001	
Reduction in Probability of Fatality, Given Fire, Between Dwellings with Only Smoke Alarms and Dwellings with Smoke Alarms and a Sprinkler System	Triangular	Minimum: 0.6700 Most Likely: 1.0000 Maximum: 1.0000	Minimum per Hall (2007) **(12)**.
Expected Number of Fatalities, per Fire, in Dwellings with Only Smoke Alarms	Normal	Mean: 0.0082 Standard Deviation: 0.0010	
Reduction in Probability of Injury, Given Fire, Between Dwellings with Only Smoke Alarms and Dwellings with Smoke Alarms and a Sprinkler System	Triangular	Minimum: 0.0000 Most Likely: 0.5679 Maximum: 0.5679	Minimum per Hall (2007) **(12)**.
Expected Number of Injuries, per Fire, in Dwellings with Only Smoke Alarms	Normal	Mean: 0.0403 Standard Deviation: 0.0029	
Reduction in Probability of Direct Uninsured Property Loss, Given Fire, Between Dwellings with Only Smoke Alarms and Dwellings with Smoke Alarms and a Sprinkler System[B]	Triangular	Minimum: 0.0000 Most Likely: 0.3166 Maximum: 0.9520	Minimum per Butry, Brown, and Fuller (2007) **(1)**. Maximum based on Scottsdale, AZ, study **(19)**.[C]
Expected Direct Uninsured Property Loss, per Fire, in Dwellings with Only Smoke Alarms	Triangular	Minimum: $0 Most Likely: $4397.96 Maximum: $9003.80	Minimum per Hall (2007) **(12)**. Maximum based on Scottsdale, AZ, study **(19)**.[D]
Expected Indirect Cost, per Fire, in Dwellings with Only Smoke Alarms	Triangular	Minimum: $0 Most Likely: $879.59 Maximum: $1800.76	Minimum per Hall (2007) **(12)**. Maximum based on Scottsdale, AZ, study **(19)**.[E]

[A] Parameters derived using NFIRS 5.0 **(2)** 2002–2005 fire incident records and calibrated using NFPA (2006) **(18)** fire statistics unless otherwise noted.

[B] Assumed equal to reduction in probability of indirect cost, given fire, between dwellings with smoke alarms and dwellings with smoke alarms and a sprinkler system.

[C] The study reports a $45 019 direct property loss in houses without sprinkler systems (although the presence of smoke alarms was not specified) and $2166 for those with, implying a 95.2 % reduction in direct property loss.

[D] See Table Footnote C above. Assuming insurance covers 80 % of direct property losses, $9003.80 is uninsured.

[E] See Table Footnote C above. Assuming indirect costs equal 10 % of direct property loss, with insurance covering 60 %, $1800.76 is uninsured.

mean present value of net benefits is positive, at $3714, although 11 % lower than the baseline estimate. Note that in all cases the minimum value for present value of net benefits is positive, indicating that the present value of benefits exceeds

TABLE X1.6 Summary Statistics of the Sensitivity Analysis[A]

	Colonial	Townhouse	Ranch
Trials	10 000	10 000	10 000
Mean PVNB	$2 467.96	$2 647.87	$3 714.38
Median PVNB	2 454.96	2 634.87	3 701.38
Minimum PVNB	703.67	883.58	1 950.08
Maximum PVNB	4 801.20	4 981.11	6 047.62
Standard Deviation	530.03	530.03	530.03

[A] Source: *Benefit-Cost Analysis of Residential Fire Sprinkler Systems* (NISTIR 7451) (Butry, Brown, and Fuller, 2007, p. 31) (**1**).

present value of installation costs. Thus, the results of the sensitivity analysis strongly support the cost-effectiveness of multipurpose network residential sprinkler systems.

X1.5 *Conclusion*—With respect to multipurpose network systems, installing sprinkler systems in newly constructed, single-family dwellings is a good investment on economic grounds from a homeowners' perspective. Brown (2005) (**9**) presented the life-cycle costs of three other residential sprinkler systems. Two of the three allowed for a backflow preventer to be installed, which requires annual professional maintenance. The annual cost was estimated at $100 to $200 per year. Installing the most expensive sprinkler system and adding the present value expense of an annually occurring maintenance charge of $200 would have increased the present value costs to $6446 for the colonial, $5995 for the townhouse, and $4812 for the ranch. The baseline value of present value net benefits would change to -$1451 for the colonial, -$1001 for the townhouse, and -$182 for the ranch. Thus, the finding that multipurpose network residential sprinkler systems are highly cost-effective does not appear to hold for other sprinkler system designs.

X2. USING NET SAVINGS TO EVALUATE ENERGY EFFICIENCY IMPROVEMENTS IN A HIGH SCHOOL BUILDING

X2.1 *Background*—A high school constructed in 2009 in the greater St. Louis, MO, metropolitan area is subjected to an economic analysis to determine if energy efficiency improvements would be cost effective. The community where the high school is located does not have an energy code requirement, so the 1999 Edition of the ASHRAE 90.1 Standard (**20**) is used as the basis for all energy-related requirements associated with the base case building design. The alternative against which the base case is analyzed uses the 2007 Edition of the ASHRAE 90.1 Standard (**21**) as the basis for all energy-related requirements associated with its building design. The ASHRAE 90.1 1999 Edition is used as the base case because it is assumed to be "common practice" for building design requirements in states with no state-wide energy code (Kneifel, 2012) (**22**). The ASHRAE 90.1 2007 Edition is used as the alternative because it provided the most comprehensive energy-related design requirements when the school was constructed. In addition, information on a similar school design constructed in Louisville, KY, indicated that the ASHRAE 90.1 2007 Edition design option was cost effective vis-à-vis the ASHRAE 90.1 1999 Edition design option (**22**). Both localities are in the same climate zone and have similar heating degree day and cooling degree day requirements.

X2.2 *Data and Assumptions*—Table X2.1 summarizes key assumptions, data elements and data values for the high school building being analyzed. The two-story building has a floor area of 130 000 ft^2 (12 077 m^2). The length of the study period is 25 years, which is less than the service life of the building but long enough to reflect a typical local government planning horizon. The economic analysis uses a 3 % real discount rate (net of general inflation or deflation) to convert future dollar values to present values. Because a real discount rate is being used, all dollar-denominated annual recurring costs and other future costs are expressed in 2009 constant dollars (dollars of uniform purchasing power exclusive of general inflation or deflation). The initial investment cost estimates for the base case, ASHRAE 90.1 1999 Edition, and the alternative, ASHRAE 90.1 2007 Edition, are based on data from RS Means CostWorks (**23**). The timing and values for all maintenance, repair and replacement costs are based on data from Whitestone Research (**24**).

X2.2.1 *Investment Cost Data*—The investment cost data reported in Table X2.1 cover the initial investment cost, the residual value of the high school building at the end of the study period in year 25, the present value (PV) of the residual value, and the PV of replacement costs for energy-related system upgrades. The initial investment cost is already expressed in PV terms, so no discounting is required. The residual value at the end of the study period is a measure of the economic value of the remaining life of the building. The residual value in year 25 is discounted to a PV through use of a single present value (SPV) factor (ASTM Discount Factor Tables Adjunct). The PV of replacement costs for energy-related system upgrades is calculated by multiplying the appropriate SPV factor based on the timing of each replacement item by the dollar value for each replacement item in that time period and summing over all time periods and all replacement items. All four sets of investment costs are separately tabulated for the base case, ASHRAE 90.1 1999 Edition, and the alternative, ASHRAE 90.1 2007 Edition.

X2.2.2 *Energy Cost Data*—The energy fuel types used in the building are natural gas for heating and electricity for cooling and lighting. Unit cost data for electricity and natural gas are based on values reported in (**22**). The product of the annual energy requirement for each fuel type and the unit cost for the fuel type equals the annual fuel cost in the first year. Although both electricity and natural gas are treated as annual expenditures, the rate at which their prices change fluctuates over time. These fluctuations are referred to as escalation rates. The escalation rates used in this analysis and the associated discount factors used to convert an annual stream of fuel costs to a PV are based on future fuel prices projected by the Energy Information Administration of the U.S. Department of Energy as reported in (**25**). The Modified Uniform Present Value

TABLE X2.1 Economic Evaluation of Energy Efficiency Improvements in a High School Building: Data and Assumptions

Data Element	Value
Floor Area	130 000 ft^2 (12 077 m^2)
Study Period	25 Years
Discount Rate	3 % (real)
Investment Cost Data	
Initial Investment Cost	
ASHRAE 90.1 1999 Edition	$15 922 252
ASHRAE 90.1 2007 Edition	$15 967 212
Residual Value (Year 25)	
ASHRAE 90.1 1999 Edition	$5 412 217
ASHRAE 90.1 2007 Edition	$5 422 416
PV Residual Value	
ASHRAE 90.1 1999 Edition	$2 584 905
ASHRAE 90.1 2007 Edition	$2 589 776
PV Replacement Costs for Energy-Related System Upgrades	
ASHRAE 90.1 1999 Edition	$366 257
ASHRAE 90.1 2007 Edition	$388 167
Energy Cost Data	
Electricity	
Electricity Unit Cost	6.96¢/kWh
Annual Electricity Cost	
ASHRAE 90.1 1999 Edition	$98 358
ASHRAE 90.1 2007 Edition	$84 515
Electricity UPV*	17.60
PV Electricity Cost	
ASHRAE 90.1 1999 Edition	$1 731 096
ASHRAE 90.1 2007 Edition	$1 487 459
Natural Gas	
Natural Gas Unit Cost	\$10.80/kft^3 (\$305.82/m^3)
Annual Natural Gas Cost	
ASHRAE 90.1 1999 Edition	$53 351
ASHRAE 90.1 2007 Edition	$53 144
Natural Gas UPV*	19.92
PV Natural Gas Cost	
ASHRAE 90.1 1999 Edition	$1 062 757
ASHRAE 90.1 2007 Edition	$1 058 629
PV Energy Cost	
ASHRAE 90.1 1999 Edition	$2 793 853
ASHRAE 90.1 2007 Edition	$2 546 088
Future Maintenance and Repair Cost Data	
PV Baseline Maintenance and Repair Costs	
ASHRAE 90.1 1999 Edition	$4 311 735
ASHRAE 90.1 2007 Edition	$4 311 735
PV Maintenance Costs for Energy-Related System Upgrades	
ASHRAE 90.1 1999 Edition	$66 151
ASHRAE 90.1 2007 Edition	$66 151
PV Repair Costs for Energy-Related System Upgrades	
ASHRAE 90.1 1999 Edition	$1 086 168
ASHRAE 90.1 2007 Edition	$1 033 632

(UPV*) factor for each fuel type is based on a 25-year study period; it is reported in Table X2.1 as 17.60 for electricity and 19.92 for natural gas. The UPV* factor is applied to the corresponding annual fuel cost to convert the annual fuel cost in the first year to a PV over the 25-year study period. The annual energy requirements for electricity and natural gas are based on simulations from the EnergyPlus software program **(26)** as reported in Kneifel (2011) **(27)** and Lippiatt et al. (2013) **(28)**. The EnergyPlus software program takes into account the integrated design nature of a building's systems. Specifically, as the thermal integrity of the building envelope is improved, the load on the HVAC system is reduced. Thus, the capacity requirements for the HVAC system may be reduced. Consequently, some of the increased investment cost for improving the thermal integrity of the building envelope may be partially offset by reductions in HVAC system cost. All energy-related costs are separately tabulated for the base case, ASHRAE 90.1 1999 Edition, and the alternative, ASHRAE 90.1 2007 Edition.

X2.2.3 *Maintenance and Repair Cost Data*—The PV of maintenance and repair costs is broken into two categories. The first category, referred to as Baseline Maintenance and Repair Costs, corresponds to the basic building; these costs exclude all energy-related system upgrades and are independent of any energy-related system upgrades. The second category covers all energy-related system upgrades. For the second category, two separate sets of values, one for maintenance costs and one for repair costs, are reported in Table X2.1. The timing and values for each category of maintenance and repair costs, baseline and energy-related upgrades, are based on data from Whitestone Research (**24**). All maintenance and repair costs are separately tabulated for the base case, ASHRAE 90.1 1999 Edition, and the alternative, ASHRAE 90.1 2007 Edition.

X2.3 *Present Value Net Savings (PVNS) Calculation*—Tables X2.2-X2.4 provide the information needed to calculate PVNS. Table X2.5 shows the calculation of PVNS. All dollar values reported in Tables X2.2-X2.5 are expressed in PV. The calculation of PVNS equals the difference between the life-cycle cost of the base case, ASHRAE 90.1 1999 Edition, and the life-cycle cost of the alternative, ASHRAE 90.1 2007 (see Eq 3 in 7.4). Tables X2.2 and X2.3 provide the basis for calculating both sets of life-cycle costs. Table X2.4 shows the calculation of both sets of life-cycle costs. Tables X2.2 and X2.3 separate the components of life-cycle cost into Investment Costs and Non-Investment Costs. Although such a separation is not necessary to calculate either life-cycle costs or the PVNS, it does support the calculation of other measures of economic performance used by decision makers. Specifically, this separation supports the calculation of the savings-to-investment ratio (Practice E964) and the adjusted internal rate of return (Practice E1057). The columns in Tables X2.2 and X2.3 are numbered to better illustrate how the resultant values are calculated. Table X2.2 reports the values used to calculate PV Investment Cost for the base case and the alternative. Column 2 contains the initial investment cost, Column 3 contains the PV of all energy-related replacement costs, and Column 4 contains the PV of the residual value. Following the procedure laid out in the life-cycle cost standard (Practice E917), PV Investment Cost equals initial investment cost (Column 2) plus PV replacement costs (Column 3) minus PV residual value (Column 4). The resultant PV Investment Cost is $13 703 604 for the base case and $13 765 603 for the alternative. Table X2.3 reports the values used to calculate PV Non-Investment Cost for the base case and the alternative. Column 2 contains PV energy cost, Column 3 contains the PV of the baseline maintenance and repair costs, Column 4 contains the PV of maintenance costs for energy-related system upgrades, and Column 5 contains the PV of repair costs for energy-related system upgrades. Following the procedure laid out in the life-cycle cost standard, PV Non-Investment Cost equals PV energy cost (Column 2) plus PV of the baseline maintenance and repair costs (Column 3) plus PV of maintenance costs for energy-related system upgrades (Column 4) plus PV of repair costs for energy-related system upgrades (Column 5). The resultant PV Non-Investment Cost is $8 257 907 for the base case and $7 957 606 for the alternative. Table X2.4 reports the life-cycle cost calculation for the base case and the alternative. The resultant life-cycle cost is $21 961 511 for the base case and $21 723 209 for the alternative. These values have been transferred to Column 1 of Table X2.5 for the base case and to Column 2 for the alternative; they provide the basis for the PVNS calculation. The resultant PVNS, reported in Column 3 of Table X2.5, is $238 302.

X2.4 *Decision*—A PVNS of $238 302 demonstrates that the additional investment in energy efficiency associated with the ASHRAE 90.1 2007 design option is cost effective. Recall that cost effectiveness only requires PVNS to be greater than zero (see 9.1). Given that the energy-related system upgrades associated with the ASHRAE 90.1 2007 design option are focused on improving energy efficiency, it is instructive to also examine the PV of energy savings associated with the ASHRAE 90.1 2007 design option. Reference to Column 2 of Table X2.3 shows that the PV of energy costs for the base case is $2 793 853 whereas the PV of energy costs for the alternative is $2 546 088. Thus, the PV of energy savings associated with the alternative is $247 765, which translates into an 8.87 % energy cost savings. The magnitude of the PV of energy savings and the percent reduction in the PV of energy costs, in conjunction with the positive PVNS, underscore the superior performance of the ASHRAE 90.1 2007 design option.

TABLE X2.2 Economic Evaluation of Energy Efficiency Improvements in a High School Building: Calculation of Investment Costs

Energy-Related Design Option	Initial Investment Cost	Present Value Replacement Costs for Energy-Related System Upgrades	Present Value Residual Value	Present Value Investment Costs
(1)	(2)	(3)	(4)	(5)=(2)+(3)-(4)
ASHRAE 90.1 1999 Edition	$15 922 252	$366 257	$2 584 905	$13 703 604
ASHRAE 90.1 2007 Edition	$15 967 212	$388 167	$2 589 776	$13 765 603

TABLE X2.3 Economic Evaluation of Energy Efficiency Improvements in a High School Building: Calculation of Non-Investment Costs

Energy-Related Design Option	Present Value Energy Cost	Present Value Baseline Maintenance and Repair Costs	Present Value Maintenance Costs for Energy-Related System Upgrades	Present Value Repair Costs for Energy-Related Systetm Upgrades	Present Value Non-Investment Costs
(1)	(2)	(3)	(4)	(5)	(6)=(2)+(3)+(4)+(5)
ASHRAE 90.1 1999 Edition	$2 793 853	$4 311 735	$66 151	$1 086 168	$8 257 907
ASHRAE 90.1 2007 Edition	$2 546 088	$4 311 735	$66 151	$1 033 632	$7 957 606

TABLE X2.4 Economic Evaluation of Energy Efficiency Improvements in a High School Building: Calculation of Life-Cycle Costs

Energy-Related Design Option	Present Value Investment Costs	Present Value Non-Investment Costs	Life-Cycle Cost
(1)	(2)	(3)	(4)=(2)+(3)
ASHRAE 90.1 1999 Edition	$13 703 604	$8 257 907	$21 961 511
ASHRAE 90.1 2007 Edition	$13 765 603	$7 957 606	$21 723 209

TABLE X2.5 Economic Evaluation of Energy Efficiency Improvements in a High School Building: Calculation of Present Value Net Savings

Life-Cycle Cost Base Case	Life-Cycle Cost Alternative	Present Value Net Savings
(1)	(2)	(3)=(1)-(2)
$21 961 511	$21 723 209	$238 302

REFERENCES

(1) Butry, D. T., Brown, M. H., and Fuller, S. K., *Benefit-Cost Analysis of Residential Fire Sprinkler Systems*, (NISTIR 7451), National Institute of Standards and Technology, Gaithersburg, MD, 2007.

(2) U.S. Fire Administration, *National Fire Incident Reporting System 5.0*, National Fire Data Center.

(3) Hall, J. R., and Harwood, B., "The National Estimates Approach to U.S. Fire Statistics," *Fire Technology*, 1989, pp. 99–113.

(4) Ahrens, M., *U.S. Experience with Smoke Alarms and Other Fire Detection/Alarm Equipment*, National Fire Protection Association, 2007.

(5) Viscusi, W. K. and Aldy, J. E., "The Value of a Statistical Life: A Critical Review of Market Estimates Throughout the World," *The Journal of Risk and Uncertainty*, Vol 27, No. 1, 2003, pp. 5–76.

(6) Zamula, W. W. *Memorandum to Gregory B. Rodgers, Costs for Non-Fatal Addressable Residential Civilian Injuries Associated with Mattress and Bedding Fires*, U.S. Consumer Product Safety Commission, 2005.

(7) Zamula, W. W., *Memorandum to Gregory B. Rogers, Costs for Non-Fatal, Addressable Residential Civilian Injuries Associated with Upholstered Furniture Fires*, 2004.

(8) Ray, D. R., Zamula, W. W., Miller, T. R., Brigham, P.A., Cohen, M. A., Douglass, J. B., Galbraith, M. S., Lestina, D.C., Nelkin, V. S., Pindus, N. M., and Smith-Regojo, P., *Societal Costs of Cigarette Fires*, U.S. Consumer Product Safety Commission Report 6, Washington, DC, 1993.

(9) Brown, M. H., *Economic Analysis of Residential Fire Sprinkler Systems* (NISTIR 7277), National Institute of Standards and Technology, Gaithersburg, MD, 2005.

(10) National Fire Protection Association, *Standard for the Installation of Sprinkler Systems in One and Two Family Dwellings and Manufactured Homes* 2002 Edition (NFPA 13D), National Fire Protection Association, 2002.

(11) Ibbotson Associates, *Stocks, Bonds, and Bills after Taxes and Inflation: Year-End 1925-2004* (PM006), 2005.

(12) Hall, J. R., Personal Communication, Assistant Vice President, Fire Analysis and Research, National Fire Protection Association, 2007.

(13) Ruegg, R. T., and Fuller, S. K., *A Benefit-Cost Model of Residential Fire Sprinkler Systems* (NBS Technical Note 1203), National Bureau of Standards, Gaithersburg, MD, 1984.

(14) Munson, M. J., and Ohls, J. C., *Indirect Costs of Residential Fires*, U.S. Government Printing Office, 0319-251/207, Washington, DC: FEMA, 1980.

(15) Hall, J. R., *The Total Cost of Fire in the United States*, National Fire Protection Association, 2004.

(16) Insurance Information Institute, *Homeowners Insurance*, 2007; available online at: http://www.iii.org/media/facts/statsbyissue/homeowners (accessed April 1, 2009).

(17) Curry, R., Personal Communication, Assistant Vice President and Actuary, Personal Property Actuarial Division, Insurance Services Office, 2007.

(18) National Fire Protection Association, *The U.S. Fire Problem: One- and Two-Family Dwelling Fires*, 2006; available online at: http://www.nfpa.org/itemDetail.asp?categoryID=953&itemid=23858&url=Research%20&%20Reports/Fire%20statistics/The%20U.S.%20fire%20problem (accessed April 1, 2009).

(19) Home Fire Sprinkler Coalition, *Automatic Sprinklers, A 15 Year Study*, Scottsdale, AZ, 2007; available online at: http://www.homefiresprinkler.org/FS/Scottsdale15.html (accessed April 1, 2009).

(20) ASHRAE/IESNA Standard Project Committee 90.1, ASHRAE 90.1-1999 Standard-*Energy Standard for Buildings Except Low-Rise Residential Buildings*, ASHRAE, Inc., 1999 Edition.

(21) ASHRAE/IESNA Standard Project Committee 90.1, ASHRAE 90.1-2007 Standard-*Energy Standard for Buildings Except Low-Rise Residential Buildings*, ASHRAE, Inc., 2007 Edition.

(22) Kneifel, J., *Prototype Commercial Buildings for Energy and Sustainability Assessment: Design Specification, Life-Cycle Costing and Carbon Assessment* (NIST Technical Note 1732), National Institute of Standards and Technology, Gaithersburg, MD, 2012.

(23) RS Means CostWorks Databases, http://www.rsmeans.com.

(24) Towers, M., Dotz, R., and Romani, L., *The Whitestone Building Maintenance and Repair Cost Reference 2008-2009* 13th Annual

Edition, Whitestone Research, Santa Barbara, CA, 2008.

(25) Rushing, A., and Lippiatt, B., *Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis–April 2009* (NISTIR 85-3273-24), National Institute of Standards and Technology, Gaithersburg, MD, 2009.

(26) EnergyPlus Example File Generator, Building Energy Simulation Web Interface for EnergyPlus, http://apps1.eere.energy.gov/buildings/energyplus/.

(27) Kneifel, J., *Prototype Commercial Buildings for Energy and Sustainability Assessment: Whole Building Energy Simulation Design* (NIST Technical Note 1716), National Institute of Standards and Technology, Gaithersburg, MD, 2011.

(28) Lippiatt, B., Kneifel, J., Lavappa, P., Suh, S., and Greig, A., *Building Industry Reporting and Design for Sustainability (BIRDS) Technical Manual and User Guide* (NIST Technical Note 1814), National Institute of Standards and Technology, Gaithersburg, MD, 2013.

ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.

This standard is copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or service@astm.org (e-mail); or through the ASTM website (www.astm.org). Permission rights to photocopy the standard may also be secured from the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923, Tel: (978) 646-2600; http://www.copyright.com/